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Water salinity variability mapping for flooded paddy plots at Kuala Kedah, Malaysia

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Abstract

Salinity is an essential parameter in rice cultivation activity. It has a significant impact on paddy growth and also the yield of paddy. However, the level of salinity concentration in paddy plots depends on the surrounding conditions. The distance of the paddy area from the coastline, the temperature and intensity of rainfall should be considered in studies involving water quality. Additionally, the tide of events is also included in this study because of the position of the study area near the coastline. Therefore, this study was conducted to assess the level of salinity in two different rice cultivation seasons and describe the level of salinity concentration using a salinity variability map using the Inverse Distance Weighted (IDW) interpolation method. The data collection activities involved water sampling at 44 water inlets for each paddy plot in 30 hectares of the study area by referring to the Day After Sowing (DAS) as the paddy's growth stage. These water samples were collected on 10 DAS, 40 DAS, and 60 DAS and subsequently tested using a portable conductivity meter namely EC500 Exstick II pH/Conductivity/Temperature Meter. Parallelly, georeference data which is latitude, longitude and elevation were gathered using Garmin GPSMAP 64s. Then, these data were analyzed using the IDW interpolation method in ArcGIS software and comes with salinity variability maps. The produced maps give an overview of the salinity concentration distribution by color scale range. Based on these salinity variability maps, the highest salinity concentration was recorded on 10 DAS and 60 DAS during Season 1 2019 and Season 2 2019, respectively for both tidal events. This result shows that the salinity concentration trend for both seasons is different due to the amount of rainfall received and the position of the paddy plot compared to the mean temperature factor.

Keywords: GIS, interpolation, *oryza sativa*, rice, saline water, seawater encroachment

Introduction

Water quality is an indicator that represents the current state of the water resources for particular purposes (Kamarudin et al., 2019; Wahab et al., 2019; Wan Mohtar, Abdul Maulud, Muhammad, Sharil, & Yaseen, 2019). One of the water quality parameters that is often taken seriously in the agricultural industry is salinity (Ahmed & Haider, 2014; Khanom, 2016). Salinity is a measure of the dissolved salts in the water. Salinity is usually highest during periods of low flows and increases as water levels decrease (Hoang, Williams, Khanna, Dale, & Mundree, 2014; Mccaffrey, 1997; Samsuddin Sah, Abdul Maulud, Sharil, A. Karim, & Abdul Nahar, 2020). Sources of salinity include urban and rural run-off containing salt, fertilizers and organic matter. However, areas in the tidal limit of rivers that flow into the sea will experience fluctuations in salinity between high and low tide (Ahmed & Haider, 2014). Tide level uncertainty is related to sea level change and global climate change (Abdul Maulud, Hasan, & Karim, 2015; Hamzah, Abd Hamid, Mohamad, Mohd Shah, & Awang, 2018; Walsh & Miskewitz, 2013). This problem is gaining attention due to the possible impact on food security in many countries (Khong, Young, Loch, & Thennakoon, 2018; Walsh & Miskewitz, 2013).

Consequently, salinity that is beyond the normal range will cause stress or even death to the plant. In addition, nutrient intake by plants is also affected and in turn causes plant growth to be stunted and the salt accumulation in the leaves affect the lifespan of the leaves (Ahmed & Haider, 2014; Munns, James, & Läuchli, 2006; Osakabe, Osakabe, Shinozaki, & Tran, 2014; Pattanagul & Thitisaksakul, 2008; Rad, Aref, & Rezaei, 2012; Samsuddin Sah et al., 2020; Xiong, 2007). If this situation persists, the yield of rice grains is declining mainly due to the development of low rice spikelet due to salt pressure (Radanielson, Gaydon, Li, Angeles, & Roth, 2018; Reddy, Kim, Yoon, Kim, & Kwon, 2017; Zhang et al., 2015).

According to Takehisa et al. (2004) almost 30% of the world's paddy cultivation area is affected by salinity and 50% of paddy production reduced because of saline water (Ma et al., 2018). As the second largest of world rice exporter, Vietnam faced the problem of the sea level rise which had a significant impact on rice production (Dam, Amjath-Babu, Bellingrath-Kimura, & Zander, 2019). This phenomenon causes seawater penetration to occur more frequently and loss of the paddy growing land (Dam et al., 2019; Smajgl et al., 2015).

Rice or the scientific name *Oryza sativa* is the staple food for most countries in Asia, the region consumes more than 80% of the world's rice including Malaysia. In 2005, the paddy industry remained the third most important sub-agricultural sector in Malaysia after the oil palm and rubber industry. According to Bohluli et al. (2014), more than 450 thousand hectares of the total agricultural land in Malaysia are used for rice cultivation. However, the number of the paddy area keep decreasing and become more challenging to meet the local demand year by year.

Currently, Malaysia strives to meet the demand for local rice by ensuring that every farmer is able to produce rice optimally (Che Omar, Shaharudin, & Tumin, 2019). Farmers, especially those who are in the Kedah coastal areas, often experience the problem of sea water entry into the paddy cultivation area. Kuala Kedah is a part of Kedah which located nearby the coastal line in the west coast of Peninsular Malaysia. Most of the farmers in this area complained about the decrement of paddy yield starting 2016 until 2019. This is due to sea water's existence in the paddy plot caused by sea water intrusion especially during high tide phenomenon and heavy rain events. A previous study by Ercan, Fauzi, & Kavvas, (2013); Reddy et al., (2017); Samsuddin Sah et al., (2020) found that the salinity concentration of more than 1100 ppm will directly stunt the paddy growth and in turn lead to a reduction in rice yields at affected areas. This also supported by

Fogliatto, Serra, Patrucco, Milan and Vidotto, (2019); Khanom, (2016) where the growth reduction due to root damage, ion toxicity, lessened nutrient and water uptake, and inhibition of photosynthesis will lead to the decrement of yields

Hence, this study was conducted to assess the level of salinity in two different seasons and describe the level of salinity concentration using salinity variability map using Inverse Distance Weighted (IDW) interpolation methods that are available in ArcGIS software for both the season. Consequently, proper planning and improvement can be seriously considered by local agencies responsible for maintaining agricultural activities as well as local livelihoods.

Method and study area

Kuala Kedah is located at the west coast of peninsular Malaysia and faces Malacca Strait. The study area involved almost 30 hectares of rice cultivation area along the low laying zone at Kuala Kedah, the coast of Kedah, which is found at the west coast of Peninsular Malaysia. These 30 hectares of paddy cultivation area is located between 6°06'41.5"N to 6°07'33.0"N and 100°16'44.7"E to 100°17'14.5"E as illustrates in Figure 1.

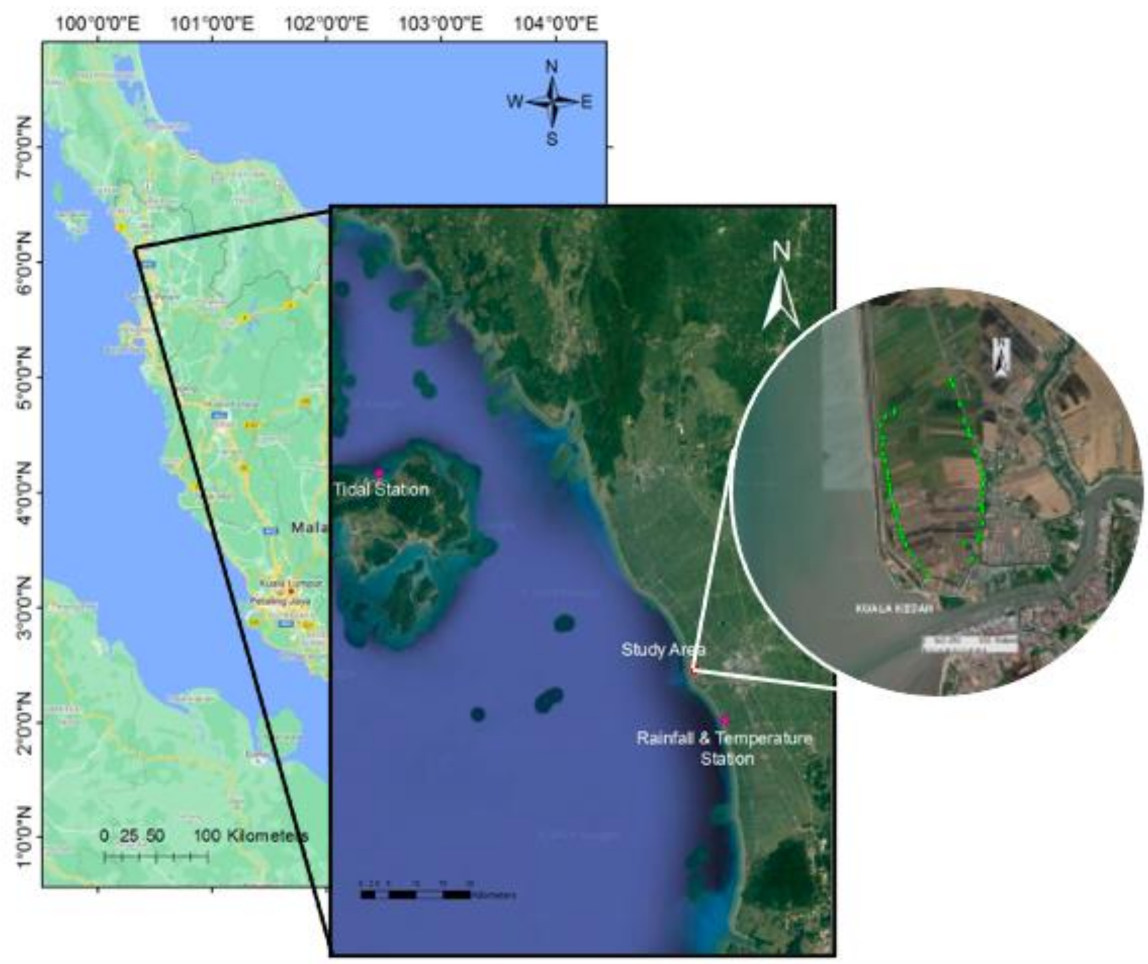


Figure 1. Location of the study area, meteorology and tidal station with observed 44 sampling point.

This study area involved 44 water inlets and was observed during low and high tide events for two different cultivation seasons in the Year 2019. The paddy cultivation for the first season is from May to August 2019, while the second session started from October 2019 to January 2020. Figure 2 illustrates the flow process in this study which consists of five (5) main elements.

Firstly, the water samples were collected at the identified 44 water inlets using a 100 ml water container by submerging the bottle 5 cm for the tillering and flowering stage as recommended by Talpur et al. (2013). In this study, the water sampling activities were planned by considering the growth stage of paddy known as tillering, flowering, and maturing stage as shown in Figure 3 by using the term “Day After Sowing” (DAS) as reference. Therefore, 10 DAS, 40 DAS, and 60 DAS were selected to represent these three growth stages and the observation has been conducted for two seasons in the Year 2019 by considering the tidal events as stated in Table 1. These three periods were selected based on the existence of water in the paddy plot. After 60 DAS, the paddy plot will be drained out to put pressure on the paddy plants to flower and subsequently produce the rice seeds. Then, the water samples were analyzed using a portable conductivity meter namely EC500 Exstick II pH/Conductivity/Temperature Meter.

Table 1. Water sampling schedule for Season 1 and Season 2 2019.

Time	Season 1 2019	Season 2 2019
10 DAS	27th May 2019	16th Oct 2019
40 DAS	28th June 2019	20th Nov 2019
60 DAS	18th July 2019	7th Dec 2019

The rainfall and temperature data during this study were retrieved from the Department of Meteorology Malaysia (DMM). The nearest DMM rain gauge station namely Station Kuala Kangkong was located at 06° 02’ N, 100° 20’ E with 20 m height from Mean Sea Level (MSL). This station was recorded average annual temperature and rainfall is 28.3°C /year and 194 mm/year, respectively while the average annual temperature and annual rainfall of 2019 in Malaysia reported by Jabatan Meteorologi Malaysia (2019) is 27.63°C and 2850 mm. In addition, the tide pattern from Langkawi Tidal Station located at 6° 26’ N, 99° 46’ was observed for both seasons.

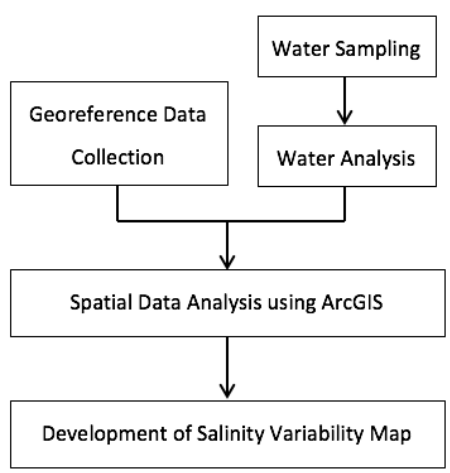
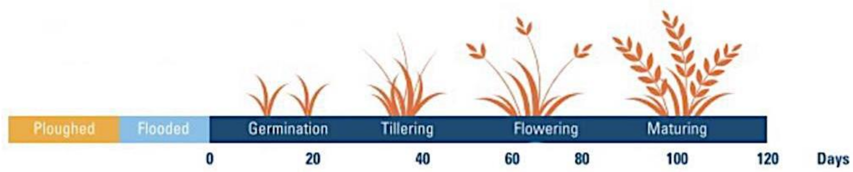


Figure 2. Study flow process.



Source: Che Omar et al. (2019)

Figure 3. General process in the rice cultivation cycle.

The georeference location of each sampling point was recorded using Garmin GPSMAP 64s. Each point consists of coordinate data (latitude, longitude, and elevation) and consequently, converted into the projected coordinate system for mapping purposes. The projected coordinate system normally is known as a coordinate system designed for on a flat and two- dimensional surface (Kennedy & Kopp, 2004).

The spatial analyst was used to transfigure the geospatial data in the form of raster and vector data in this study. The data of salinity concentrations as well as their respective georeference locations, were imported into ArcGIS software. ArcGIS platform was created and developed to visualize and present the data spatially. Specifically, ArcGIS 10.7.1 was used to produce the spatial maps of salinity variability. These maps were generated by using the Inverse Distance Weighted (IDW) interpolation method in ArcGIS spatial analyst tool to represent the current water quality status in the paddy plots. This method is one of the most applied and deterministic interpolation techniques because fast and easy to compute, and straightforward to interpret the unknown points by calculated with a weighted average of the values available at the known points (Abdullahi et al., 2017; Bhunia, Shit, & Maiti, 2018).

The IDW is widely used and well known in computing the unknown value using the nearby weighted values as equations below.

$$Z(x) = \frac{\sum_{i=1}^{n} W_i Z_i}{\sum_{i=0}^{n} W_i} \tag{1}$$

$$W_i = \frac{1}{d_i^k} \tag{2}$$

where Z(x) is the estimated value at an unknown point, and Zi is the observed value at the point i. While, Wi is the weight value at point i, and di is the distance between point i and the unknown point; moreover, k is the power variable (Wu, Mossa, Mao, & Almulla, 2019).

Sapna et al. (2018) and Gunarathna et al. (2016) stated that the best interpolation method to estimate the water quality parameter especially electric conductivity (EC) and pH is the IDW method. This statement aligned with findings by Yang et al. (2020) was indicated that this interpolation method is an effective tool to estimate surface water quality. Although IDW is a fast method (Achilleos, 2008), best method in interpolation (Mirzaei & Sakizadeh, 2016) and accurate in the present the actual data, it is sensitive to existing outliers in the dataset and does not issue any error indications (Wu, Hung, & Patton, 2013). The main uncertainty issue as raised by Achilleos (2008) is inequality surface elevation of sampling points due to the long distance between the points. However, this issue can be easily neglected in this study. This is because the surface elevation at flooded paddy fields is normally a flat area.

Furthermore, the IDW interpolation approach is more applicable and better than another method such as Kriging and Spline (Yang, Xie, Liu, Ji, & Wang, 2015) in estimating the water quality value, especially in rice cultivation area (Pirmoradian, Rezaei, Davatgar, Tajdari, & Abolpour, 2010). In addition, according to Tanjung, Syahreza and Rusdi (2020), this approach is described as the best method to interpolate the water electrical conductivity (EC), which is also represents the salt concentration in water.

Therefore, in this study, the IDW interpolation method was preferred to interpolate the spatial distribution of salinity and finally, twelve salinity variability maps were produced for both tidal events during these two seasons. All these maps were colored by designated unique value for each raster data. However, there are some limitations in this study that have been identified which is this study does not involve any analysis of paddy yield either according to the paddy plot or the entire area. Then, the study period only involved only one cycle of wet and dry seasons.

Results and discussion

Environment condition: Rainfall, mean temperature, tidal

According to Figure 4, the highest average monthly rainfall and mean temperature was recorded on May 2019, while the lowest average monthly rainfall and mean temperature were detected on January 2020 and December 2019, respectively. However, during the Season 1-2019, this area received more rainfall compared to the Season-2 2019. In this case, the observation was conducted in two different seasons which is wet season occurs from May 2019 until August 2019, while dry season occurs from Oct 2019 until Jan 2020.

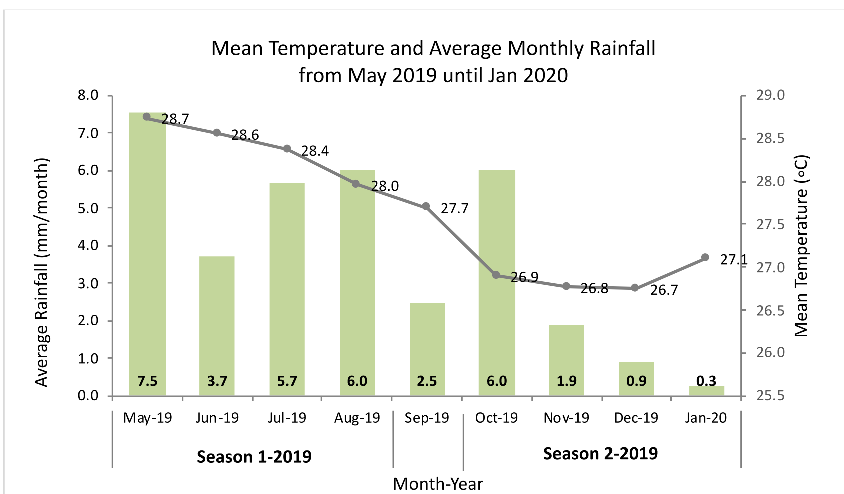
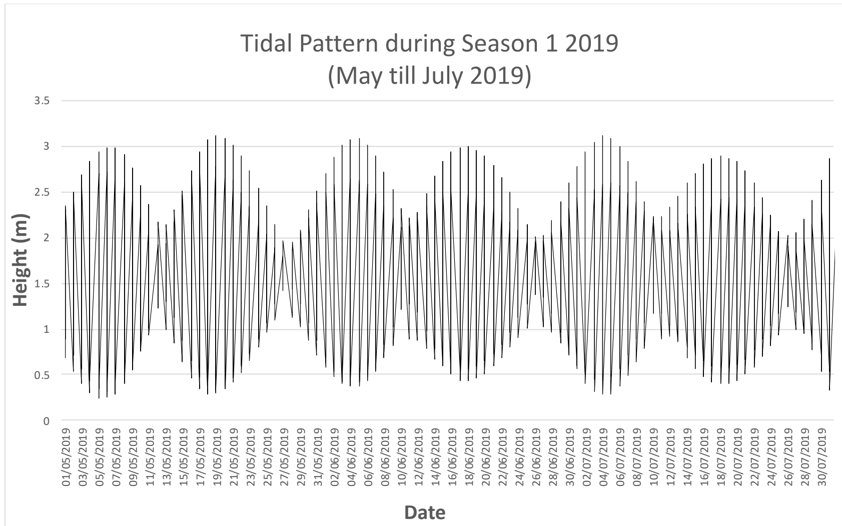


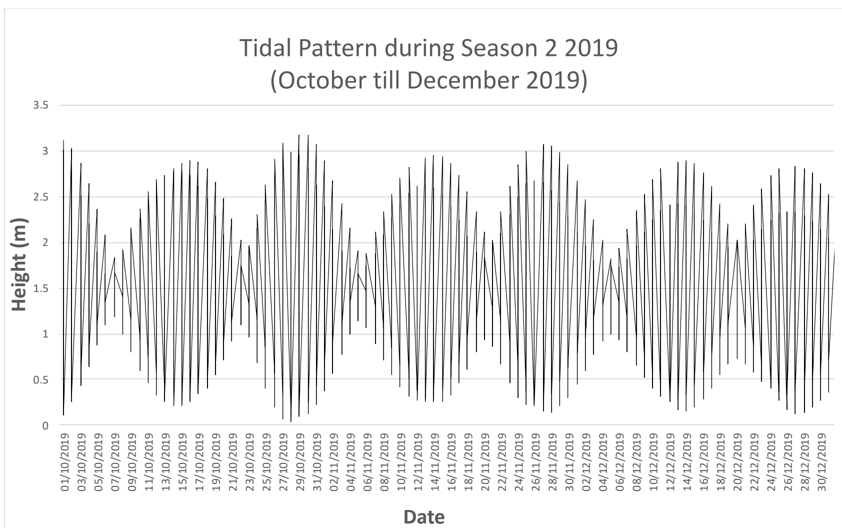
Figure 4. Mean temperature and average monthly rainfall.

Subsequently, a tidal events pattern was observed during Season 1 2019 and Season 2 2019. This data was extracted from Tide Table 2019 by National Hydrographic Centre, Malaysia. Figure 5a shows the pattern with maximum height recorded on 19th May 2019 and 04th July 2019 at 1235hrs and 1319hrs, respectively with 3.11 m height while the minimum height recorded on 05th and 19th May 2019 at 0619hrs and 0643hrs with 0.24 m height.

However, during Season 2 2019, the maximum and minimum height was spotted on 29th Oct 2019 at 0036hrs with 3.18 m height and the minimum height was spotted on 28th October 2020 at 1821hrs with 0.04 m height as shown in Figure 5b.



(a) Season 1 2019



(b) Season 2 2019

Source: National Hydrographic Centre (2019)

Figure 5. Tidal pattern for year 2019.

Salinity Variability Maps for Season 1 and Season 2 2019

Salinity variability maps were produced using ArcGIS 10.7.1 by using the interpolation spatial analyst tool. The salinity concentration was classified in five main ranges based on the article by Prince (2019) as illustrates in Table 2.

Table 2. General salinity concentration range for water.

Group	Concentration (mg/L)	Status
1	0 - 456	Very Low
2	457 - 700	Low
3	701 - 1100	Moderate
4	1100 - 1500	High
5	> 1500	Very High

Source: Prince (2019)

Figure 6 and Figure 7 show the distribution of salinity concentration during low and high tide events for Season 1 2019, respectively. This clearly indicates that the salinity concentration decreases from the early stage to the later stage of paddy growth. The 10 DAS maps show more than 70% of the study area faced very high salinity concentration with a value of more than 1100 ppm, which is represented by brown and pink color range. This situation illustrates that the existence of saltwater in paddy fields is due to tidal events and also the driving factor which is heavy rain due to the highest tide height and the amount of rainfall recorded in May 2019 which fell during the 10 DAS period as reported by (Lian, Xu, & Ma, 2013; Shaha, Cho, & Kim, 2013). They found that these two factors played a significant role in the flood phenomenon, especially in the estuary and coastal areas.

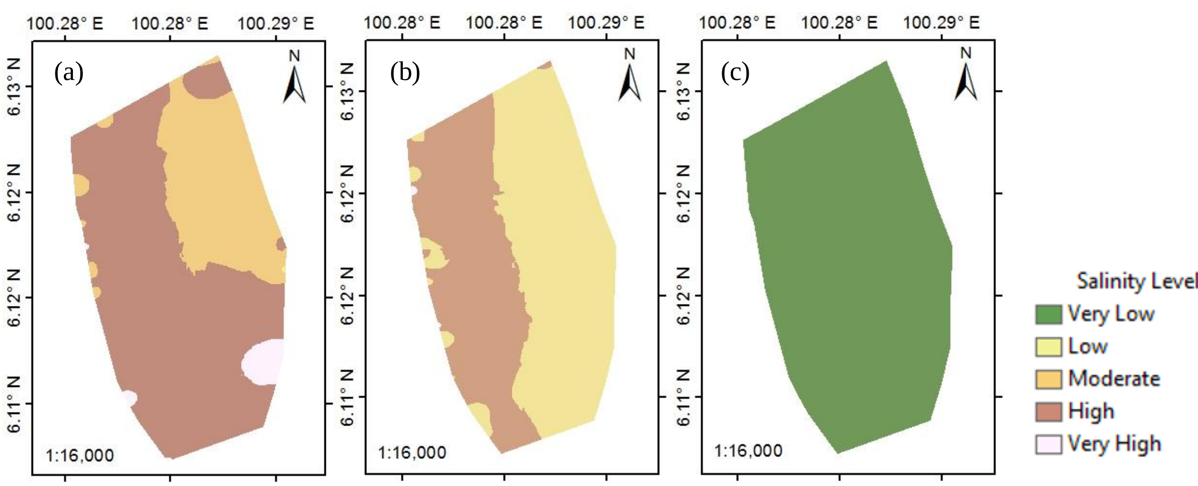


Figure 6. Water salinity variability maps during low tide events on (a) 10 DAS, (b) 40 DAS, and (c) 60 DAS for Season 1-2019.

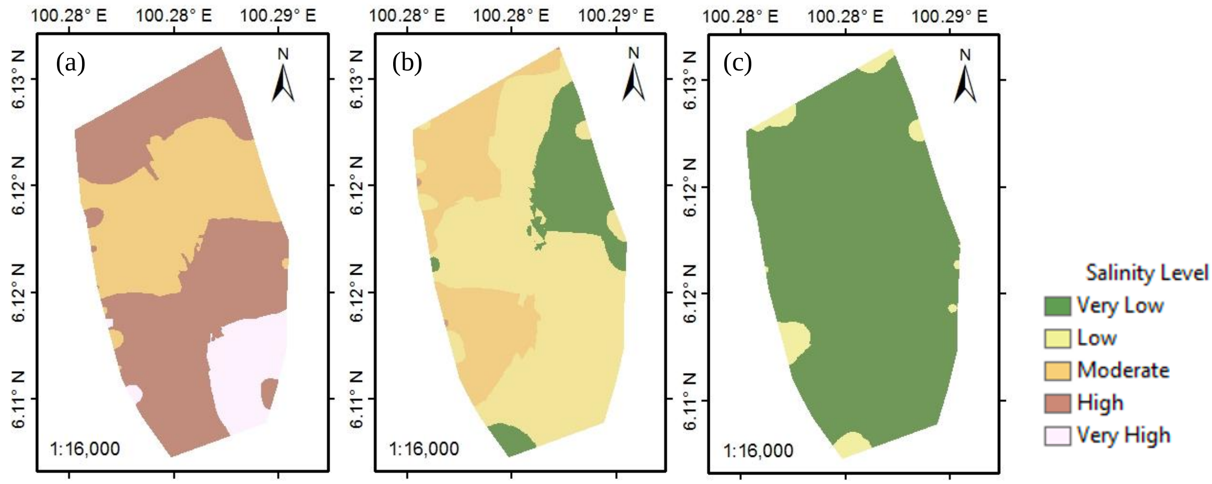


Figure 7. Water salinity variability maps during high tide events on (a) 10 DAS, (b) 40 DAS, and (c) 60 DAS for Season 1-2019.

However, during Season 2 2019, the trend changed as salinity concentrations increased throughout the rice cultivation cycle. According to Figure 8 and Figure 9, the highest salinity concentrations were spotted on 60 DAS for both tidal events which is contradicting with the high tide events occurred on 10 DAS period (October 2019). This situation occurred due to the lower rainfall intensity on 60 DAS that produces higher salinity concentration in this area. The salinity concentration in water significantly affected by the dry season as claimed by Abdullah, Rak and Wei, (2018) and Yan et al. (2015).

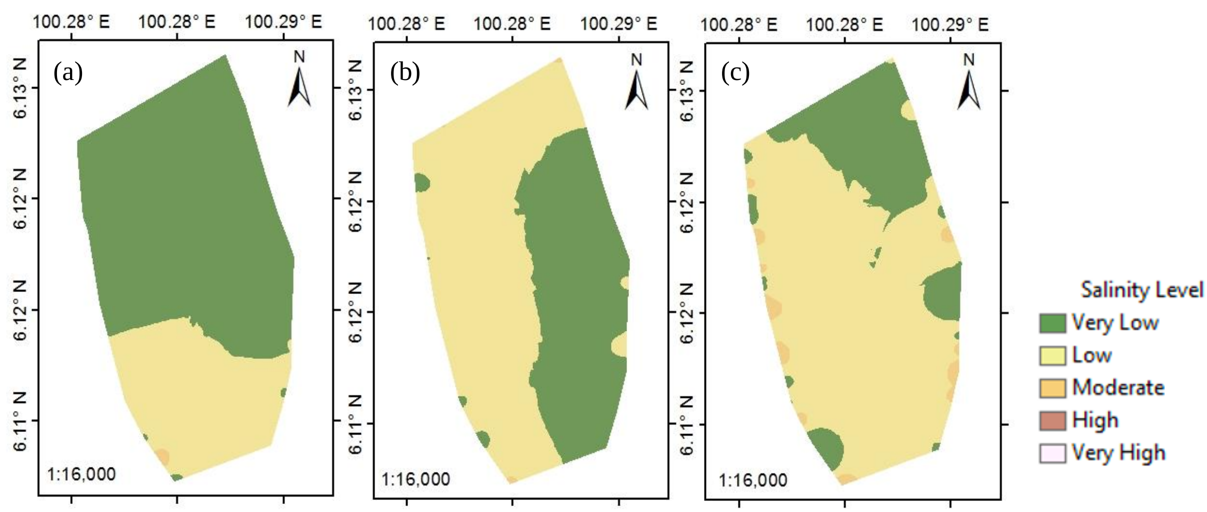


Figure 8. Water salinity variability maps during low tide events on (a) 10 DAS, (b) 40 DAS, and (c) 60 DAS for Season 2 2019.

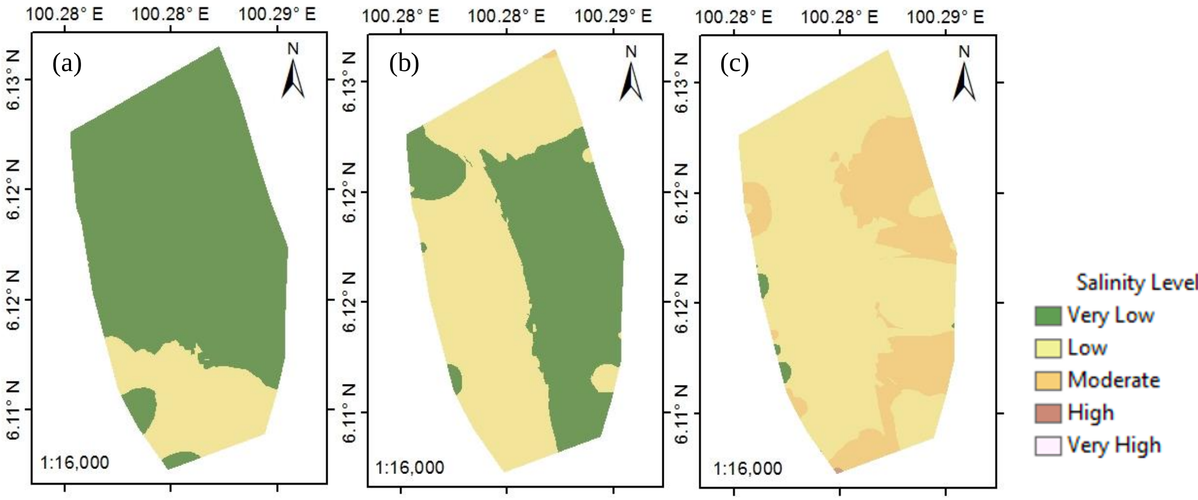


Figure 9. Water salinity variability maps during high tide events on (a) 10 DAS, (b) 40 DAS, and (c) 60 DAS for Season 2 2019.

Generally, during the 10 DAS period for both seasons and tidal events, the highest salinity concentrations are spotted in the downstream area of the Kedah River estuary. There are tidal gates that are commonly used to prevent seawater from entering the body of water nearby and also used to drain the highlands if it receives heavy rainfall (Walsh & Miskewitz, 2013). However, when heavy rains and high tides occur, the possibility for seawater to enter the river is very high due to rising sea levels. That is caused by the concentration of salinity is higher in this area (Fatema, Omar, & Isa, 2016). In addition, during this period, the river is used directly for the purpose of irrigating rice plants in the area.

Nevertheless, during the 40 DAS and 60 DAS, salinity concentrations were seen concentrated on the left side of the diagram for both seasonal and tidal events. This area is located closest to the coastal line and indicates that seawater penetration occurs while the area receives high rainfall. This result aligned with the report by Geng & Boufadel (2017) were found that rainfall intensity significantly affected pore water salinity near the beach surface. The movement of salinity particles to the supratidal zone occurs more rapidly when receiving more rainfall at one time (Yu et al., 2020).

In general, the supratidal zone known as spray zone was defined as a zone near the coastal but higher than the level of high tide. It is sometimes splashed but not inundated or submerged by seawater (Darmawan, Saputra, Wiadnya, & Gusmida, 2018). This zone is only flooded by seawater during spring tides or possibly large storm waves splash over the coastal zone. Therefore, salinity concentrations should be monitored and controlled to avoid yield loss as reported by Radanielson et al. (2018) and Reddy et al. (2017), with concentrations over 1100 ppm, yield shortages can reach 1 ton for each a hectare area.

Overall, salinity concentration trends for both seasons are different. Based on boxplots in Figure 10, clearly expresses the salinity concentration are decreasing throughout the growth stages for Season 1 2019. On the other hand, Figure 11 shows the trend for Season 2 2019 is seen as the contrary of the previous season. The concentration of salinity indicates an increase from the early stage to the later. As reported by Fatema et al. (2016), the water quality parameters, including salinity were significantly different between spring and neap tide events. This findings also aligned with studies by Uncles and Stephens (2011) and Purnaini, Sudarmadji and Purwono (2018).

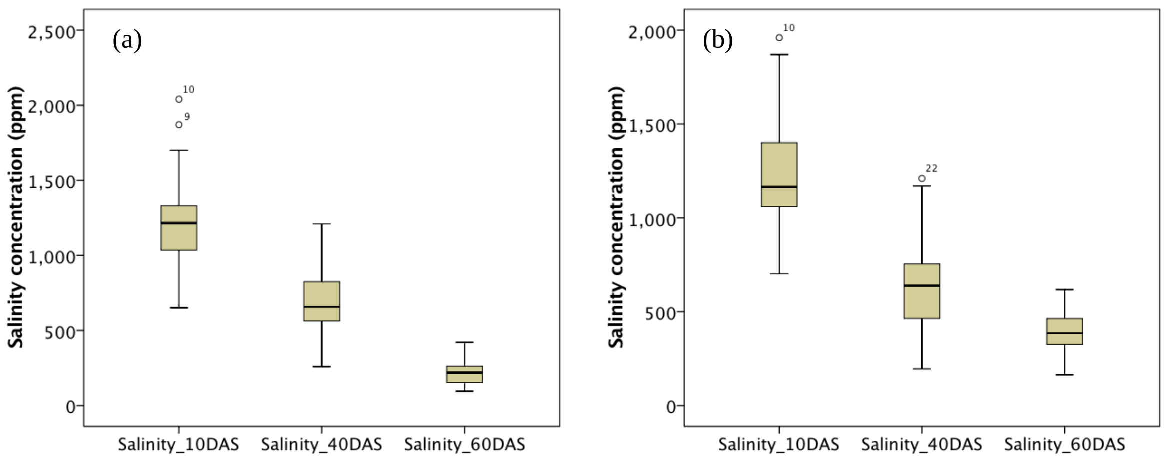


Figure 10. Boxplots of salinity concentration data during (a) low tide and (b) high tide events on Season 1-2019, respectively.

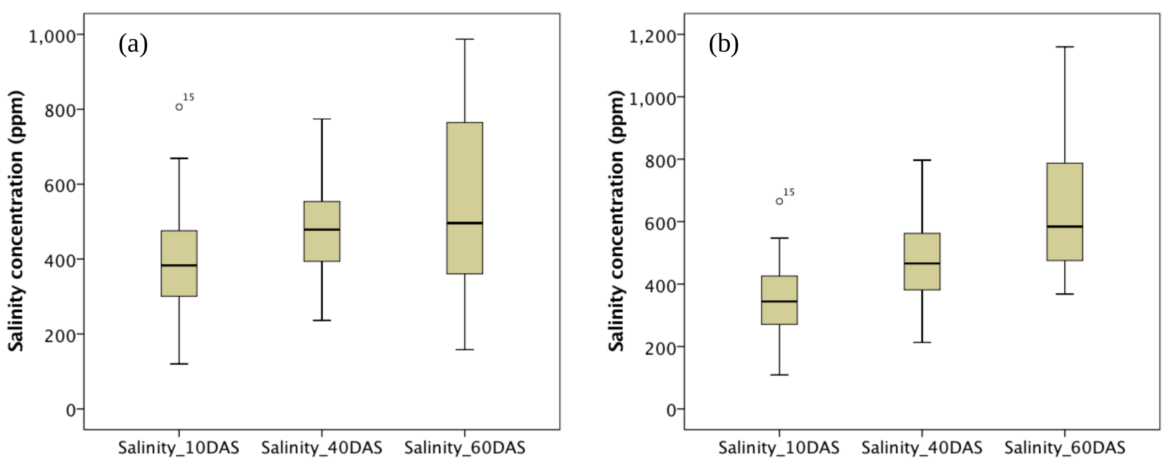


Figure 11. Boxplots of salinity concentration data during (a) low tide and (b) high tide events on Season 2-2019, respectively.

Based on findings by Liu et al. (2020), salinity concentrations can be directly diluted by rainfall. This means that the salinity concentration will be reduced if it receives high rainfall. Additionally, these researchers also found that salinity was less sensitive to temperature compared to rainfall. However, in this study, the higher rainfall gives a higher value of salinity concentration especially during Season 1 2019 which contrary with the findings reported by Liu et al. (2020). This is due to the location of the study area which is located approximately 200m from the shoreline and the seawater easily penetrated into the paddy plots during heavy rainfall and also the high tide events, as discussed in earlier paragraphs (Geng & Boufadel, 2017).

Conclusion

Salinity variability maps have been developed using the Spatial Analyst Tool in ArcGIS for these paddy plots. The highest salinity concentration was recorded on 10 DAS during Season 1 2019 for both tidal events. During this period, paddy plots have received water directly from irrigation canals with high concentrations of salinity due to seawater penetration. Conversely, during Season

2 2019, the highest reading of salinity concentration was spotted on 60 DAS. This is because in Season 1 2019, this area received a high amount of rainfall compared to Season 2 2019, which results in the movement of salty particles from the sea occurs faster. Overall, the salinity concentration trends for both seasons using are different. In conclusion, salinity concentrations were remarkably affected by the amount of received rainfall, especially in the supratidal zone area. Conversely, mean temperature not relatively affect the salinity level in the samples water observed due to the geography factors of the study area.

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